U. Michigan

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Dr. John T. Holloway
Acting Director
Office of Research Grants and Contracts
Code SC
National Aeronautics and Space Administration
Washington 25, D. C. 20546

Subject: Progress Report for NASA Grant NsG-86-60 for period ending 30 November 1965

Gentlemen:

The progress made during the period from 1 June 1965 through 30 November 1965 on NASA Grant NsG-86-60 is as follows:

As reported previously, the results of a series of experiments, involving the acceleration of spherical particles in the flow behind the shock wave in a shock tube, have shown the same trend of drag coefficient (C_D) versus Reynolds number (R_e) as is classically accepted for spheres in steady, incompressible flow. However, the C_D data from the shock tube were substantially higher than the classical values and exhibited a large scatter and a sensitivity to Mach number (M) at values of M below 0.3. The principal emphasis during the subject reporting period has been an investigation of the causes of these effects.

A careful examination of the shock tube experiment has shown that the effects of boundary layer and wake unsteadiness, free stream turbulence, particle rotation, and particle acceleration are negligible in the current investigations. However, particle surface roughness was found to influence significantly the particle drag data. This roughness effect was found by using very small spherical particles (0.004 to 0.016 inches in diameter) where nominally "smooth" surfaces become aerodynamically rough; i. e., the size of the surface roughness becomes significant when compared to the thickness of the boundary layer on the sphere. Sphere drag data, obtained by using carefully cleaned, lapped sapphire balls (surface finish on the order of 5 micro-inches), approached the classical drag data and exhibited much less of the scatter and none of the Mach number dependence that was found by using relatively rough gunpowder balls and commercial glass beads. The rougher particles showed an increase of C_D with M at values of M below 0.3. Finally, these roughness effects occurred at values of R_e significantly below the conventional critical value. These results have been reported by B. P. Selberg as a professional thesis in "Shock Tube Determination of the Drag Coefficient of Small Spherical Particles;" this report has been submitted for publication as a NASA Contractor's Report.

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An evaluation of the performance of the shock tube in which the above investigations were made has shown that, at values of free stream M greater than about 0.5 or 0.6, increasing boundary layer effects and decreasing test times preclude its use to obtain C_D data in the slip and compressible flow regimes. Two experiments are being investigated for replacing the shock tube. In one experiment, a magnetically suspended spherical particle will be placed in a small, subsonic, steady-state wind tunnel. This approach yields the advantages of the wind tunnel without support interference effects and, in conjunction with the Laboratory's vacuum system, will permit a fairly deep penetration of the subsonic, compressible slip flow regime with both smooth and rough particles.

The second experiment is expected to replace the "free trajectory" provisions of the shock tube that are required in studies involving charged and burning particles. This experiment uses an expansion tube; the particles are accelerated in the flow generated by an unsteady centered expansion wave propagating into a long tube. The principal advantage, compared to the shock tube, of this approach is the long test time available; current results in a prototype tube 10 feet long show a test time of 15 milliseconds at an M of 0.5 compared to a 4 millisecond test time for the shock tube at the same value of M.

Sincerely yours,

K. R. [signature] for

J. A. Nicholls
Project Supervisor

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